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ANNUAL TECHNICAL REPORT

(For period 1 April 1976 through 31 March 1977)

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Contract N00014-72-C-0234

LOW-ENERGY PARTICLE EXPERIMENT

Prepared by

Space Sciences Laboratory
Lockheed Palo Alto Research Laboratory
Lockheed Missiles & Space Company, Inc.

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This program is directed toward an improved understanding of the sources and the energization, transport and loss processes associated with the low-energy (keV) plasmas in the earth's magnetosphere. A low-energy particle experiment was launched on the Air Force S3-3 satellite in July of 1976. The experiment is operating completely successfully and has already made several major discoveries about previously unknown ionospheric acceleration mechanisms and the composition of the ring current.

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ANNUAL TECHNICAL REPORT
(For period 1 April 1976 through 31 March 1977)

Contract N00014-72-C-0234
LOW-ENERGY PARTICLE EXPERIMENT

This program is directed toward an improved understanding of the sources and the energization, transport and loss processes associated with the low-energy (keV) plasmas in the earth's magnetosphere, particularly as they relate to ionospheric perturbations and ionospheric-magnetospheric coupling.

The experiment is operating completely successfully and has already made several major discoveries about previously unknown ionospheric acceleration mechanisms and the composition of the ring current.

The principal result has been the discovery of large fluxes of energized ionospheric ions streaming up the magnetic field lines from the ionosphere. This discovery establishes the existence of a major new ionospheric-magnetospheric coupling phenomenon. The characteristics of the phenomenon point to parallel electric fields as the immediate cause of the accelerated ions. These results and those of the ONR companion experiment on S3-3, which makes in situ measurements of the electric fields, put on a firm basis the many recent speculations and inferences relating to large electric potential differences parallel to the geomagnetic field lines in the magnetosphere.

Another important result was the discovery of a second type of ionospheric acceleration mechanism which preferentially accelerates the perpendicular component of the ion velocity.

A third important result was the first direct measurement of the composition of the storm-time ring current. In the energy range from 1-16 keV the main phase ring current has been found to be primarily composed of H^+ and O^+ ions.

More detailed discussions of the results will be found in the appendix.

Our principal activities during the present reporting period were:

1. The provision of technical planning and liaison for the on-orbit support of the ONR-118 payload.

2. The performance of surveys of approximately 200 flight data tapes.

3. The detailed analysis of several events in order to establish the principal characteristics of the newly discovered phenomena.

4. The publication and presentation of the initial results to the scientific community.

Publications and Presentations

General reviews of these exciting new results and related earlier work will be given in invited presentations at the Spring 1977 American Geophysical Union Meeting in Washington, D. C. (by Dr. R. G. Johnson) and at the Third General Assembly of IAGA in Seattle in August 1977 (by Dr. E. G. Shelley). In addition to the invited reviews, nine contributed papers have been submitted to these and other meetings and three written papers have been or shortly will be published. A bibliography of these publications follows and the relevant abstracts, preprints and reprints are included in the appendix.

E. G. Shelley

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Lockheed Palo Alto Research Laboratory

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"Satellite Observations of an Ionospheric Acceleration Mechanism," by E. G. Shelley, R. D. Sharp, and R. G. Johnson, EOS, 57, 992, 1976.

"Characteristics of Upward-Flowing, Energetic (keV), Ionospheric Ions during a Magnetically-Disturbed Period," by R. G. Johnson, R. D. Sharp, and E. G. Shelley, EOS, 57, 993, 1976.

"Recent Results of Energetic Ion Composition Measurements in the Magnetosphere," by R. D. Sharp, R. G. Johnson, and E. G. Shelley, presented at the International Symposium on the Magnetosphere and Its Environment, Christchurch, New Zealand, January 1977.

"Energetic (keV) Ion Composition Observations on the S3-3 Satellite," by R. G. Johnson, R. D. Sharp, and E. G. Shelley, invited paper to be presented at the special session on the S3-3 satellite at the Spring 1977 meeting of the American Geophysical Union in Washington, D. C., May 1977.

"Angular Distribution Characteristics of Up-Streaming Energetic (keV) O^+ and H^+ Ions," by A. Ghielmetti, R. G. Johnson, E. G. Shelley, and R. D. Sharp, submitted for presentation at the Spring Meeting of the American Geophysical Union in Washington, D. C., May 1977.

"Electrostatic Potential Differences Along Magnetic Field Inferred from Satellite Measurements of Electron and Ion Distributions," by J. B. Cladis and R. D. Sharp, submitted for presentation at the Spring Meeting of the American Geophysical Union in Washington, D. C., May 1977.

"The Morphology of Upward-Flowing Field-Aligned Energetic Ion Fluxes," by A. Ghielmetti, E. G. Shelley, R. G. Johnson, and R. D. Sharp, submitted for presentation at the IAGA General Assembly, Seattle, Washington, August 1977.

"Observation of Ions of Ionospheric Origin in the Storm-Time Ring Current," by R. G. Johnson, R. D. Sharp, and E. G. Shelley, submitted for presentation at the IAGA General Assembly, Seattle, Washington, August 1977.

"Distribution of Electrostatic Potential Along Magnetic Field Inferred from Observations of Electron and Ion Fluxes," by J. B. Cladis and R. D. Sharp, submitted for presentation at the IAGA General Assembly, Seattle, Washington, August 1977.

"Observations of Ions of Solar Wind Origin in the Inner Magnetosphere," by E. G. Shelley, R. D. Sharp, and R. G. Johnson, submitted for presentation at the IAGA General Assembly, Seattle, Washington, August 1977.

"Recent Results of Energetic Ion Composition Measurements," by E. G. Shelley, invited review paper to be presented at *Session SIII 1b, Heavy Ions of Ionospheric Origin in the Magnetosphere*, at the IAGA General Assembly in Seattle, Washington, August 1977.

APPENDIX

RELEVANT PUBLICATIONS AND PRESENTATIONS

SATELLITE OBSERVATIONS OF AN IONOSPHERIC ACCELERATION MECHANISM

E. G. Shelley, R. D. Sharp, and R. G. Johnson

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Abstract. A satellite-borne energetic ion mass spectrometer experiment has detected fluxes of O^+ and H^+ ions flowing up out of the ionosphere in the auroral and polar regions. The observed ions have energies in the keV range, narrow pitch-angle distributions aligned along the magnetic field direction and peak flux intensities of the order of 10^8 (cm^2-sec-sterad-keV)$^{-1}$. The observations were made at altitudes between 5000 and 8000 km on both the day and nightsides of the earth.

Introduction

The existence of large fluxes of energized ionospheric ions with energies of up to 12 keV in the magnetosphere was established by mass spectrometer observations on the satellite 1971-89A [Shelley et al., 1972]. This was a 3-axis stabilized spacecraft and so no information on the angular distributions of the ions was obtained. The measurements were in the loss cone at altitudes of about 800 km and represented the precipitating component of the ion fluxes. The existence of an ionospheric acceleration mechanism leading to the energization of the observed ions was inferred from the measurements, but no direct observations of the mechanism in operation were obtained. Other evidence implying the existence of such a mechanism was obtained from electrostatic analyzer experiments on ATS-6 and IMP-7. Although these instruments could not directly determine the species of the measured ions, their probable ionospheric origin was inferred from their morphological characteristics. Field-aligned structures of low-energy ions referred to as "source cone structures" were reported by Mauk and McIlwain [1975]. Bouncing clusters of heavy ions of probable ionospheric origin were reported by McIlwain [1976]. Ion fluxes interpreted as streaming O^+ were detected by the IMP-7 experiment at geocentric radial distances of $\approx 35\ R_E$ in the magnetotail [Frank et al., 1976].

Observations

This letter presents preliminary results from a newly-orbited ion mass spectrometer experiment on a spinning spacecraft which for the first time allows detailed pitch-angle distribution measurements of ions with identifiable mass-per-unit-charge. The spacecraft is in an elliptical polar orbit with apogee in the polar regions at ≈ 8000 km altitude and so allows a search for newly accelerated ions streaming up the field lines from the ionosphere below. The instrument is an improved version of the one flown on satellite 1971-89A [Shelley et al., 1972] and like that instrument consists of three individual mass spectrometers operating in different energy ranges. Each spectrometer acquires a 30-channel mass-per-unit-charge spectrum at a single energy-per-unit-charge every second. Every 16 seconds, this energy-per-unit-charge setting is cycled through one of four values, allowing a 12-point energy spectrum to be acquired every 64 seconds. (The 12 measured energy-per-unit-charge values are 0.50, 0.68, 0.94, 1.28, 1.76, 2.4, 3.3, 4.5, 6.2, 8.5, 11.6, and 16.0 keV.) The satellite is spinning about an axis perpendicular to the orbital plane at about 3 RPM and the spectrometers are oriented perpendicular to the spin axis so that an angular distribution measurement at three energies over an angular range of about 290° is acquired every 16 seconds. The experiment also contains four electron detectors operating in the keV range similar to those described by Reed et al. [1969].

Scans of the mass spectrometer data from the first few orbits for which data were available showed several examples of ions streaming up the field lines. Two examples, one on the dayside at high latitudes and one in the nightside auroral zone were selected for this preliminary report. Both examples occurred during comparatively quiet magnetic periods.

Figure 1 shows a segment of data from the low-energy mass spectrometer acquired in the northern polar region at a local time of about 1430. The relative responses of the O^+ and H^+ ions are plotted versus time and can be compared with the pitch angle determined from the on-board magnetometer shown in the upper panel. The energy-per-unit-charge of the measured ions is also indicated. One sees sharply peaked pitch-angle distributions for both O^+ and H^+ corresponding to ions streaming up the field lines from the ionosphere. A preliminary estimate of the absolute flux intensity corresponding to the peak proton response illustrated is $\approx 10^8$ (cm^2-sec-sterad-keV)$^{-1}$ at 1.28 keV. The lowest panel of Figure 1 shows the response of the electron detector which sampled the energy range $0.37 < E < 1.28$ keV. The deep minima corresponding to the atmospheric loss cone are clearly evident at the same locations as the ion peaks.

The mass-per-unit-charge spectrum of the ions measured at 1.28 keV per charge during one of the angular scans through the loss cone region is shown in Figure 2. One sees that there are significant H^+ and O^+ fluxes but no evidence of the helium ions which have been detected on other occasions with the 1971-89A experiment [Johnson

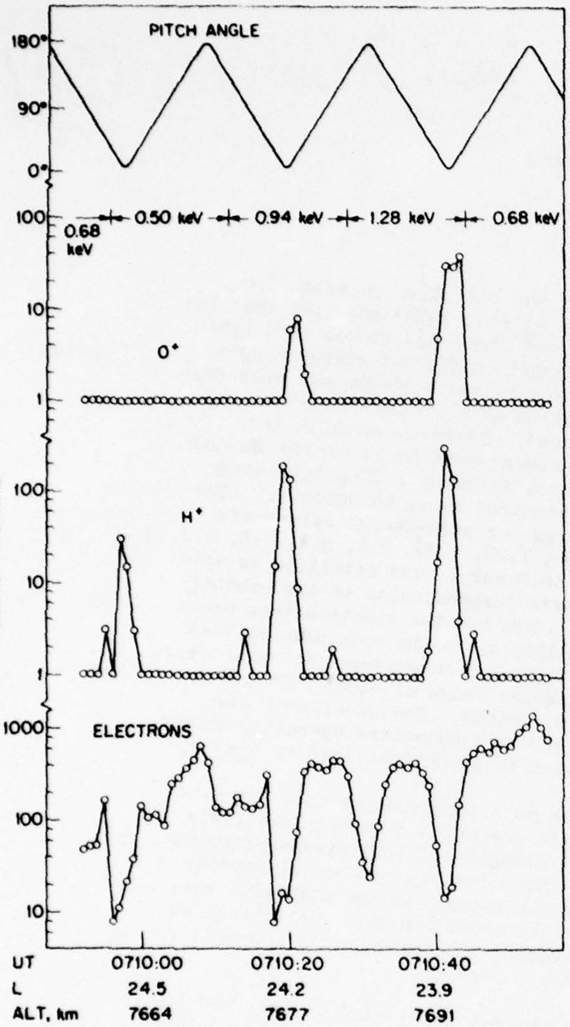

Fig. 1 Data from Revolution 67 on July 17, 1976. The upper panel shows the pitch angle of the measured particles. The two center panels show data from the mass spectrometer at the indicated energies, and the lower panel shows electron fluxes in the energy range from 0.37 to 1.28 keV. The relative temporal precision of the plots is about one second.

et al., 1974; Sharp et al., 1974]. During the period illustrated in Figure 1, the higher energy mass spectrometer channels also showed evidence of field-aligned fluxes with energies of up to 4.5 keV for O^+ ions and up to 2.4 keV for protons. Those fluxes were substantially weaker than those shown, at the lower energies, in Figure 1. The K_p value for the period of these observations was 1. The entire day of July 17 was relatively quiet with a $\Sigma K_p = 11^-$.

The second example shown in Figure 3 is from the northern auroral zone at a local time of about 21 hours on July 13. The format is similar to Figure 1. Again one sees both O^+ and H^+ fluxes streaming up the field lines. The mass-per-unit-charge spectrum during the second of the two ion peaks is shown in Figure 4. The H^+ peak on this occasion was significantly narrower than expected from the response function of the instrument and than was observed in the first event shown in Figure 2. This probably was due to temporal or spatial fluctuations during the four-second period of the measurement and is possibly indicative of turbulence associated with the acceleration mechanism. The K_p value during the period of these observations was 2^-. The ΣK_p for the entire day of July 13 was 9^-.

Summary and Conclusions

We can infer some characteristics of the ionospheric acceleration mechanism from these preliminary observations. It is effective in both the dayside and nightside ionospheres, over a wide range of latitudes, even during magnetically quiet times. It operates below ≈ 6000 km. It has a relatively high occurrence frequency. Individual events have a latitudinal-width/temporal-duration corresponding to up to a minute of satellite travel with possible fine scale turbulent structure superimposed. The process is not accompanied by strong pitch-angle diffusion since the observed ions are well collimated along the field line. The process accelerates both H^+ and O^+ in comparable intensities and to roughly comparable energies with other species being as yet unobserved. The peak differential flux intensities observed at about 1 keV are of the order of 10^8 (cm^2-sec-sterad-keV)$^{-1}$. All of the cases observed to this time occurred in regions of precipitating auroral electrons. In the cases studied, field-aligned ion fluxes were not observed returning from the other hemisphere. It is not clear yet whether the observations are taking place on open or closed field lines or both. (The electron fluxes in each of the examples shown here have indications of an additional loss cone at 180° in some spins and not in others.)

We can further conclude from these observations

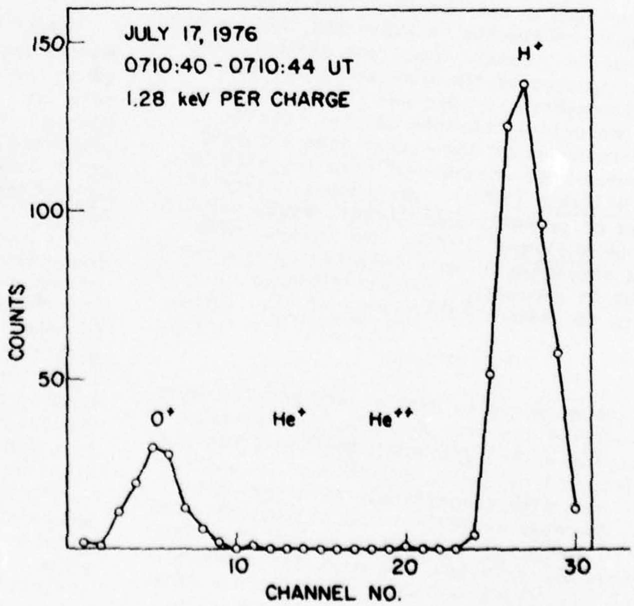

Fig. 2 Mass-per-unit-charge spectrum on Revolution 67.

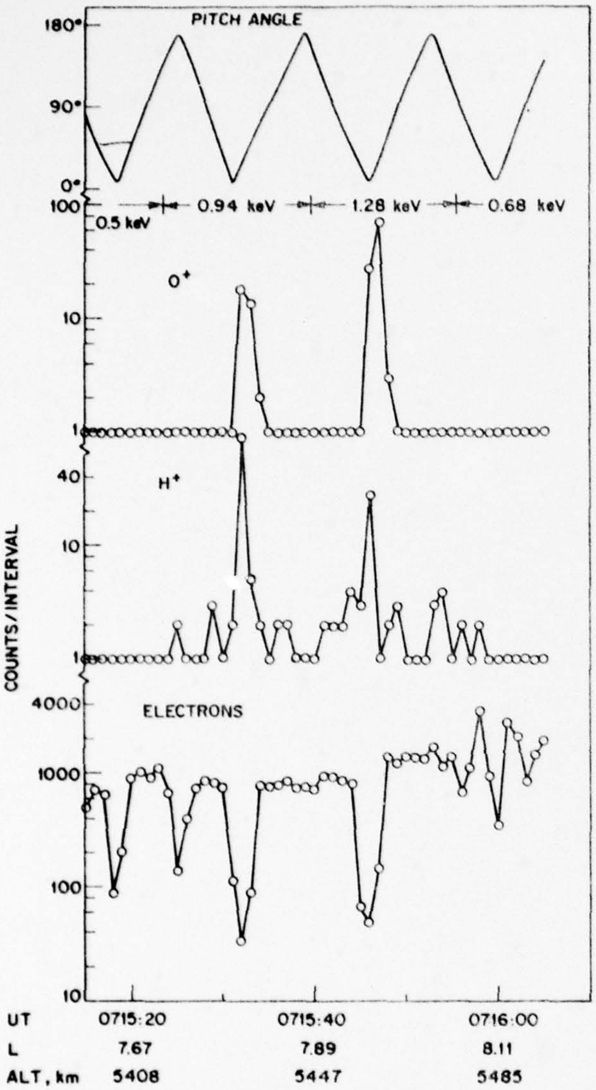

Fig. 3 Data from Revolution 35 on July 13, 1976. The quantities plotted are the same as in Fig. 1.

that the ionosphere is a significant source of magnetospheric proton fluxes as well as energetic O^+ ions and that further acceleration to higher energies than is observed here is needed to attain the ion energies seen in the precipitating population during storms [Sharp et al., 1976].

In conclusion, we have made direct observations of the products of an ionospheric acceleration mechanism and described some of the characteristics of that mechanism. Further studies of its morphology and of the detailed mass, energy, and angular distributions of the accelerated ions will follow.

Acknowledgments. This experiment was supported by the Office of Naval Research under Contract N00014-72-C-0234. We would like to thank T. C. Sanders, J. D. Matthews, J. D. McDaniel, and E. Hertzberg for their contribution to the design and construction of the spectrometer, and D. L.

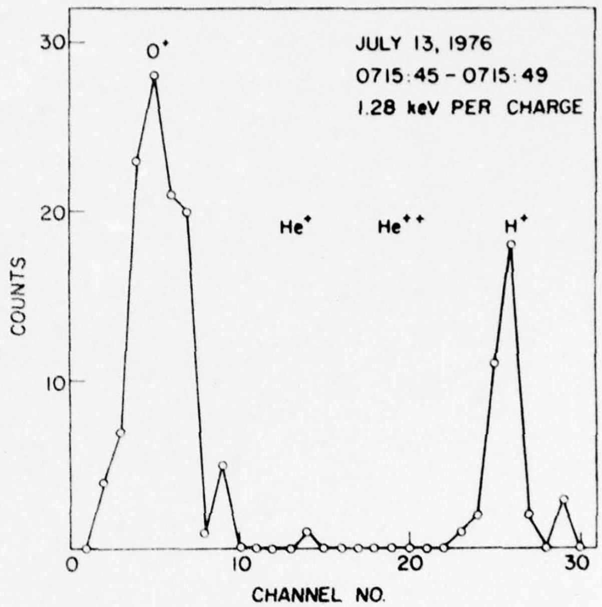

Fig. 4 Mass-per-unit-charge spectrum on Revolution 35.

Carr for his assistance with the data reduction. We also gratefully acknowledge the cooperation of Mr. A. B. Hazard of the Navy Space Systems Activity.

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BRIEF REPORT

OBSERVATION OF AN IONOSPHERIC ACCELERATION MECHANISM PRODUCING ENERGETIC (keV) IONS PRIMARILY NORMAL TO THE GEOMAGNETIC FIELD DIRECTION

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BRIEF REPORT

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ABSTRACT

O^+ ions with energies of approximately 1 keV have been observed flowing upward out of the ionosphere with a pitch-angle distribution having a minimum along the magnetic field direction and maxima in about the 130°-140° range. The measurements were obtained with an energetic ion mass spectrometer experiment on the satellite 1976-65B at an altitude of about 7600 km in the northern dayside polar cusp. The data are interpreted as resulting from a mechanism which accelerates ambient ionospheric ions in a direction perpendicular to the geomagnetic field.

INTRODUCTION

In a previous publication [Shelley et al., 1976] we reported the observation of intense fluxes of upward-flowing ions with energies in the keV range and narrowly collimated pitch-angle distributions aligned along the magnetic field direction. Such pitch-angle distributions are suggestive of an acceleration mechanism primarily acting on the component of the ion's velocity parallel to the magnetic field, such as field-aligned DC electric fields. In this brief report, we show an example of a different class of phenomena, i.e., an ionospheric acceleration mechanism which acts on the perpendicular component of the ion's velocity. Our preliminary analysis indicates that this process is observed much less frequently than the process which acts primarily on the ion velocity component

parallel to the magnetic field.

The measurements to be described were obtained from an experiment on the satellite 1976-65B which is in an elliptical polar orbit with apogee at about 8000 km altitude. The satellite is spinning at 3 RPM with its spin axis perpendicular to the orbital plane. The particle spectrometers are mounted with their view directions perpendicular to the spin axis. The experiment consists of 3 ion mass spectrometers and 4 electron spectrometers similar in design to those described previously [Shelley et al., 1972; Reed et al., 1969]. The energy ranges and geometric factors of the electron spectrometers are listed in Table 1. The ion mass spectrometers each acquire a 30-channel mass-per-unit-charge spectrum at a single energy-per-unit-charge every second. The energy-per-unit-charge setting is cycled through 4 values every 64 seconds, remaining on each step for 16 seconds. Thus, a 12-point energy spectrum is acquired from the 3 spectrometers every 64 seconds. These 12 measured energy-per-charge values are also listed in Table 1.

The data to be described here were acquired during a traversal of the dayside cusp on July 29, 1976 at a magnetic local time close to noon and an altitude of about 7600 km. Large fluxes of upward flowing O^+ ions were observed during several satellite spins over the interval from 74.7° to 76.4° in invariant latitude. The fluxes had a characteristic pitch-angle distribution with a minimum along the magnetic field direction. The data from the lowest energy mass spectrometer (CXA1) plotted against universal time are shown in Figure 1. The arrows indicate those times (once per spin) when the instrument was oriented nearly parallel to the magnetic field and pointing downward. The ordinate is counts per 3/16-second counting interval from the m/q = 16 portion of the mass-per-charge spectrum. The O^+ flux level corres-

ponding to the peak response equals approximately 5 x 10^6 (cm^2-sec-sterad-keV)$^{-1}$. The occasional gaps are due to loss of data. The switching of the energy-per-charge setting of the spectrometer every 16 seconds is indicated in the figure. The observed O^+ fluxes were quite soft being generally below the sensitivity threshold level of the higher energy spectrometers. The fact that no O^+ fluxes were detected during that portion of the spin cycle when the instrument was pointing upwards shows that the observed particles were not trapped ions mirroring at lower altitudes but were injected from some source region below the satellite.

The relationship of the upward flowing O^+ to the polar cusp ion and electron fluxes is illustrated in Figure 2. The abscissa shows universal time on July 28, 1976; geographic longitude and latitude; altitude in kilometers; invariant latitude in degrees and magnetic local time. The four lowest panels show the logarithm of the counts per half-second counting interval for the electron spectrometers. The next panel indicates the pitch angle of the measured particles (180° pitch angle corresponds to particles moving upward out of the ionosphere antiparallel to B). The two upper panels show the logarithm of the counts from ions with m/q = 1 or 16 as indicated, summed once per second from the three mass spectrometers, giving an approximate relative measure of the total flux of the relevant species.

A possibly significant feature which can be seen in Figure 2 is that incoming fluxes of both electrons and protons maximize in the latitudinal region of the O^+ acceleration. In searching for a causative agent for this acceleration therefore, it is tempting to look to these particles for some evidence of interactions, or the lack thereof, below the satellite

in the region of the ionospheric acceleration process. In examining the data in Figure 2 we see that the proton fluxes in this region generally show a well-defined loss cone while the electrons show significant evidence of loss cone filling. This probably indicates that the electrons are experiencing substantial pitch-angle diffusion and that the range of pitch angles depleted of electron fluxes by atmospheric interactions is partially filled in by pitch-angle scattering below the satellite. The proton data, on the other hand, are indicative of a lack of such strong pitch-angle scattering.

In order to make a more detailed examination of the ion pitch-angle distributions in the latitudinal region of the acceleration process we have selected for further analysis the data from the three consecutive spins of the satellite where the fluxes were most intense. These are indicated as spins 1, 2, and 3 in *Figure* 1. The upper panel of Figure 3 shows the O^+ data from CXA1 during this period plotted versus pitch angle. Time varies from left to right along each curve, and the times at which the instrument cycles from one energy step to another are indicated. There are occasional missing points due to gaps in the acquired data. The pitch-angle distributions maximize in the range of about 130°-140°. This is consistent with a mechanism operating below the satellite which primarily accelerates the perpendicular component of the velocity of the ambient ionospheric O^+, producing energetic ions with essentially 90° pitch angle. These ions would then mirror and move upward obeying the first adiabatic invariant, so that the maximum in their pitch-angle distribution folds outward into the characteristic distribution observed at the satellite altitude. If this simple model is valid, the acceleration process had its maximum intensity at an altitude of 4000 to 5000 km.

The two lower panels in Figure 3 show the $m/q = 1$ data for the two lowest energy spectrometers during this same period. One sees that ions are observed coming from the upper hemisphere as well as from below the satellite. Thus the upward-moving H^+ could result from ions incident from the cusp and mirroring below the spacecraft. Since temporal and spatial fluctuations in the ion flux levels can occur on a scale commensurate with the spin rates one cannot rule out the possibility that some component of the observed fluxes is newly-accelerated H^+ of ionospheric origin.

In order to investigate this question further and to search for minor ionic species, we examined the mass-per-unit-charge spectrums of the observed ions summed over two different ranges of pitch angle during this same period. One range was set to include the newly-accelerated O^+ ions and any other ions which might have originated or mirrored in that same altitude region. The second range included all ions incident from the upper hemisphere plus those mirroring below the satellite at altitudes above the acceleration region. These spectrums for the three spectrometers are illustrated in Figure 4. The most dramatic difference between the two sets of spectrums is, of course, the presence of the O^+ in the acceleration region in CXA-1. One sees in the incident flux region in all 3 spectrometers the He^{++} ions which are the clear signature of the solar wind origin of the cusp particles. There is very little He^{++} apparent in the acceleration region. This might be taken to imply that some fraction of the protons in this region were accelerated from the ionosphere, since in that case they would be unaccompanied by He^{++}. Unfortunately, however, the difference in the He^{++}/H^+ ratios between the two regions is not definitively

statistically significant. In the incident flux region the He^{++}/H^{+} count ratio summed over the three mass-per-unit-charge spectrums equals 0.052 ± 0.011 while in the acceleration region the same ratio equals 0.024 ± 0.013. No significant evidence is apparent for He^{+} which could be either newly accelerated or result from charge exchange of the incident He^{++}.

One additional test which can be made for evidence of newly accelerated H^{+} ions in the acceleration region, or for evidence of some interaction and energy loss of the incident H^{+} ions, is to examine the H^{+} energy spectrums averaged over the two regions. Since the spectrometers cycle through energies only about once per spin it is not possible to obtain a full twelve-point spectrum simultaneously, and in a region of structured fluxes such as we have here it was felt that such a spectrum would not be significant. In any one spin, however, a three-point spectrum is obtained from the three spectrometers simultaneously and these spectrums, averaged over adjacent portions of the "acceleration" and "incident flux" regions of pitch angle are illustrated in Figure 5.

One sees that thereis no significant evidence for sources or interactions of the H^{+} ions in the O^{+} region.

SUMMARY AND CONCLUSIONS

We have examined some characteristics of an ionospheric acceleration mechanism which operates on the component of the ion velocity perpendicular to the magnetic field. The process was found to occur in a region of strong incident proton and electron fluxes from the polar cusp. It had a maximum

intensity at an estimated altitude of ≈ 4000-5000 km. The cusp protons did not exhibit evidence of a strong interaction in the acceleration region while the cusp electrons had significantly filled loss cones which we have tentatively interpreted as the result of pitch-angle diffusion. An alternative explanation could be the existence of a parallel electric field below the spacecraft which could raise the mirror altitude of the measured electrons above the atmospheric interaction region. If such a field exists then the altitude at which the mechanism shows its maximum intensity may be lower than the above estimate indicates. If the mechanism is triggered by some threshold level of electron fluxes, that level is of the order of 10^9 e^-/cm^2-sec.

ACKNOWLEDGMENTS

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Table 1

DETECTOR CHARACTERISTICS

Detector	Particle	Energy (E, in keV) or Energy-Per-Unit-Charge	GΔE (cm^2-sec-str-keV)
CMEA	Electrons	$0.07 \rightarrow 0.24$	1.2×10^{-6}
CMEB	Electrons	$0.35 \rightarrow 1.1$	6.5×10^{-6}
CMEC	Electrons	$1.6 \rightarrow 5.0$	1.9×10^{-5}
CMED	Electrons	$7.3 \rightarrow 24$	6.5×10^{-5}
CXA1	Ions	0.50, 0.68, 0.94, 1.28	Depends on ion species $\approx 7\text{x}10^{-5}E$
CXA2	Ions	1.76, 2.4, 3.3, 4.5	
CXA3	Ions	6.2, 8.5, 11.6, 16.0	

FIGURE CAPTIONS

Fig. 1 O^+ data from the lowest energy mass spectrometer (CXA1) at the times indicated, on July 29, 1976. The arrows indicate those times (once per spin) when the instrument was oriented nearly parallel to the magnetic field and pointing downward. The numbers above the panels are the energy-per-unit-charge setting of the spectrometer (in keV).

Fig. 2 Survey plots showing the ion and electron data during the traversal of the polar cusp on July 29, 1976.

Fig. 3 Ion data showing detailed pitch-angle dependence of the low-energy O^+ and H^+ fluxes during the three spins indicated in Figure 1.

Fig. 4 Mass-per-unit-charge spectrums averaged over two different ranges of pitch angle (see text for details).

Fig. 5 Energy-per-unit-charge spectrums averaged over two different ranges of pitch angle (see text for details).

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Shelley, E. G., R. D. Sharp, and R. G. Johnson, Satellite observations of an ionospheric acceleration mechanism, Geophys. Res. Letters, 3, 654, 1976.

Shelley, E. G., R. G. Johnson, and R. D. Sharp, Satellite observations of energetic heavy ions during a geomagnetic storm, J. Geophys. Res., 77, 6104, 1972.

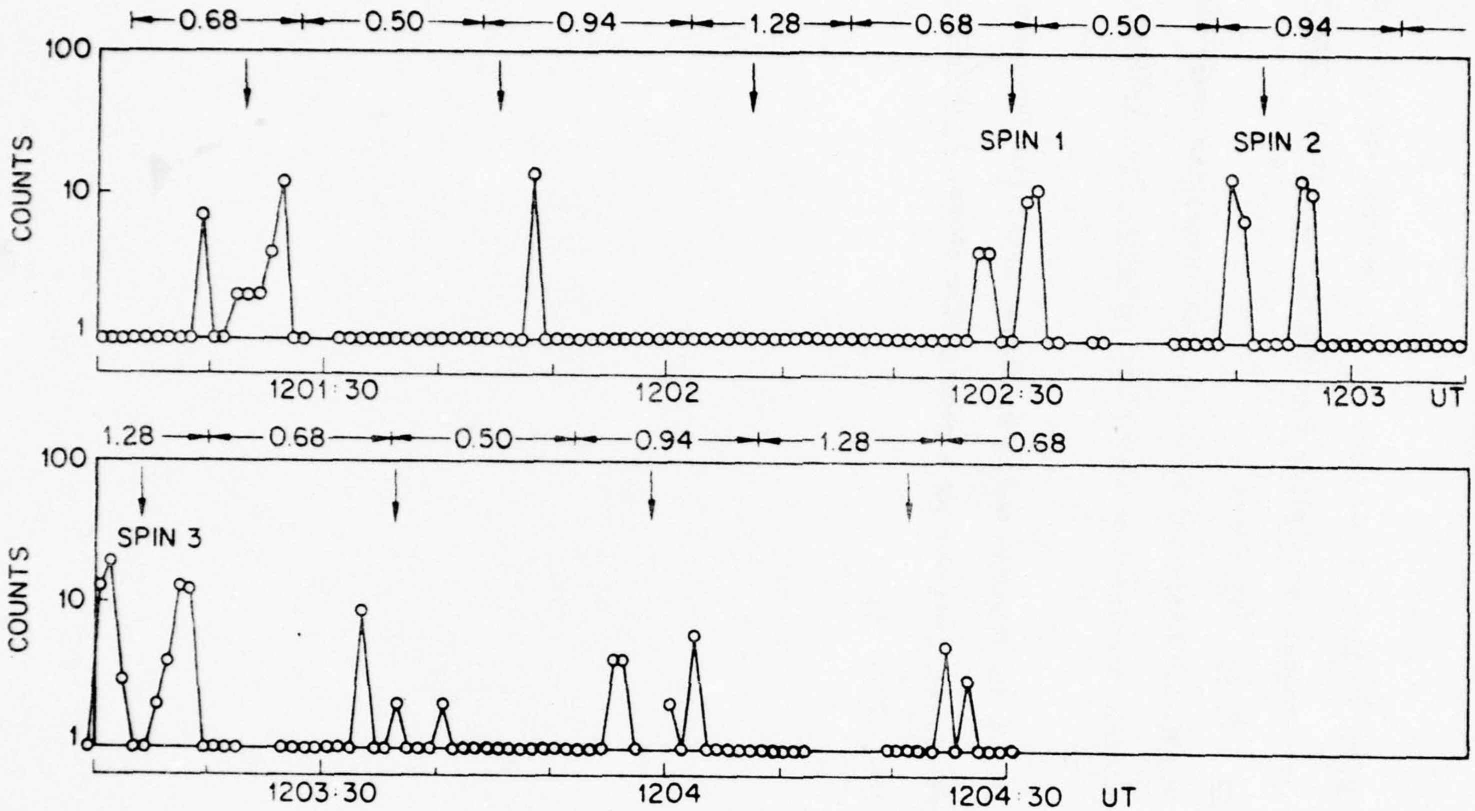

0.68
0.50
0.94
1.28
0.68
0.50
0.94
100
10
1
COUNTS
SPIN 1
SPIN 2
1201:30
1202
1202:30
1203
UT
1.28
0.68
0.50
0.94
1.28
0.68
100
10
1
COUNTS
SPIN 3
1203:30
1204
1204:30
UT

FIGURE 1

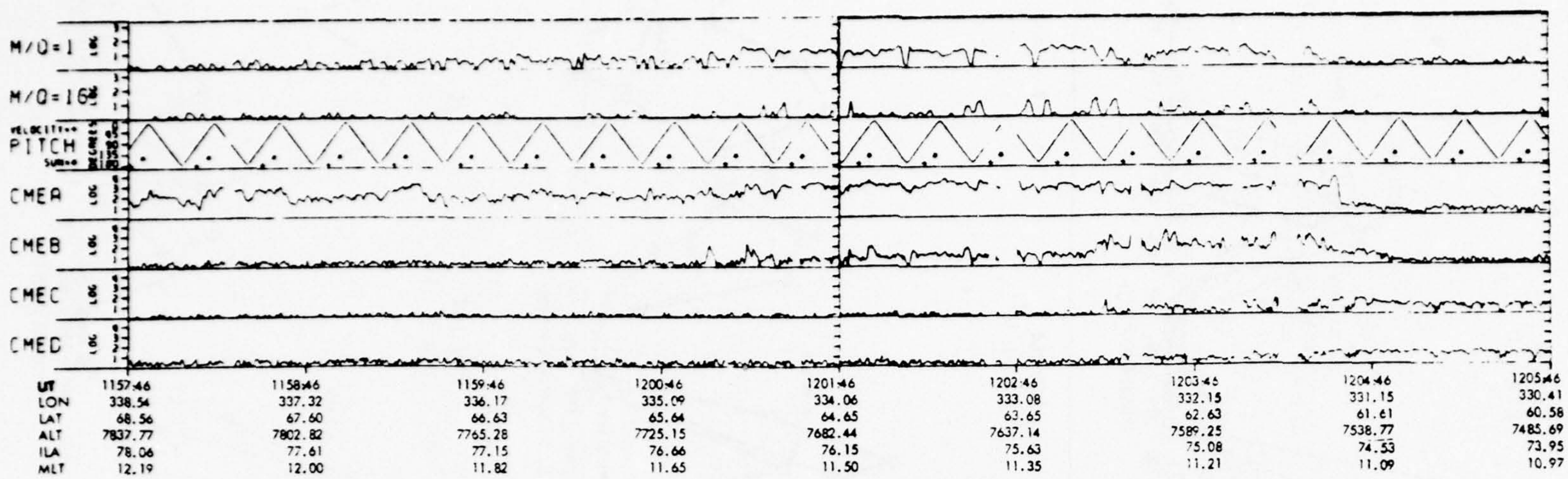
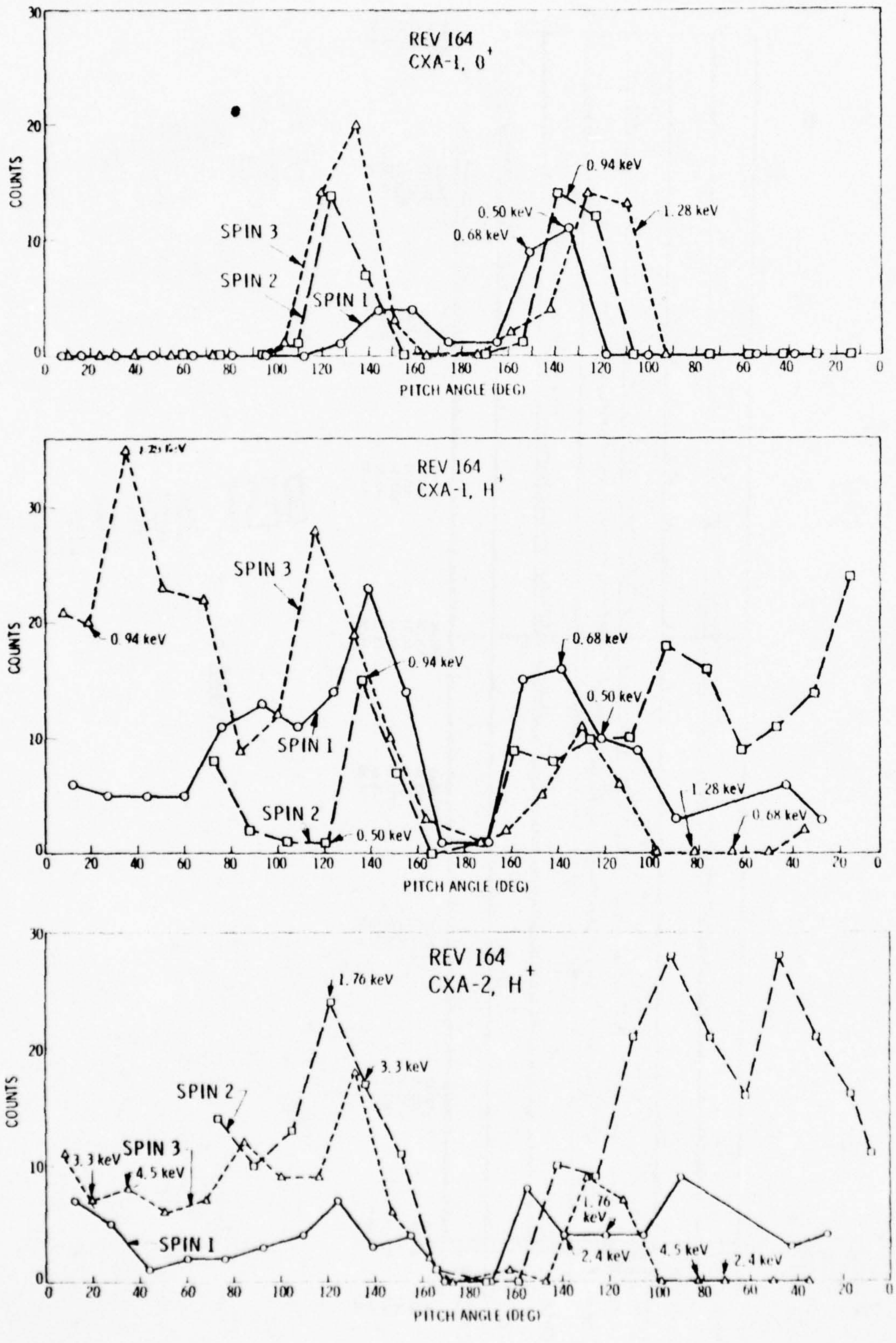

M/O=1
M/O=16
PITCH
CMEA
CMEB
CMEC
CMED
UT 1157:46 1158:46 1159:46 1200:46 1201:46 1202:46 1203:46 1204:46 1205:46
LON 338.54 337.32 336.17 335.09 334.06 333.08 332.15 331.15 330.41
LAT 68.56 67.60 66.63 65.64 64.65 63.65 62.63 61.61 60.58
ALT 7837.77 7802.82 7765.28 7725.15 7682.44 7637.14 7589.25 7538.77 7485.69
ILA 78.06 77.61 77.15 76.66 76.15 75.63 75.08 74.53 73.95
MLT 12.19 12.00 11.82 11.65 11.50 11.35 11.21 11.09 10.97

FIGURE 2



REV 164
CXA-1, O^+
COUNTS
SPIN 3
SPIN 2
SPIN 1
0.94 keV
0.50 keV
0.68 keV
1.28 keV
PITCH ANGLE (DEG)
REV 164
CXA-1, H^+
COUNTS
0.94 keV
SPIN 3
SPIN 1
SPIN 2
0.50 keV
0.94 keV
0.68 keV
0.50 keV
1.28 keV
0.68 keV
PITCH ANGLE (DEG)
REV 164
CXA-2, H^+
COUNTS
1.76 keV
3.3 keV
SPIN 2
SPIN 3
3.3 keV
4.5 keV
SPIN 1
1.76 keV
2.4 keV
4.5 keV
2.4 keV
PITCH ANGLE (DEG)

FIGURE 3

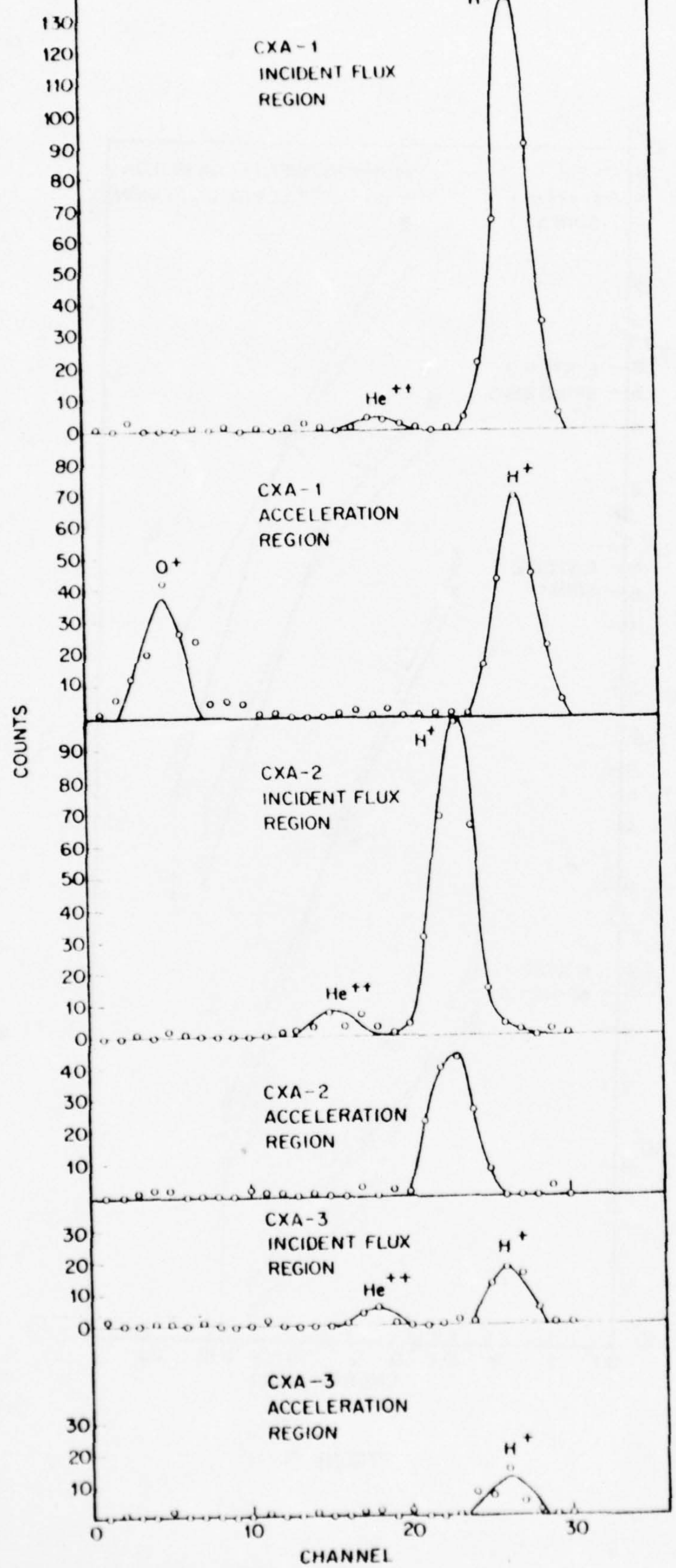
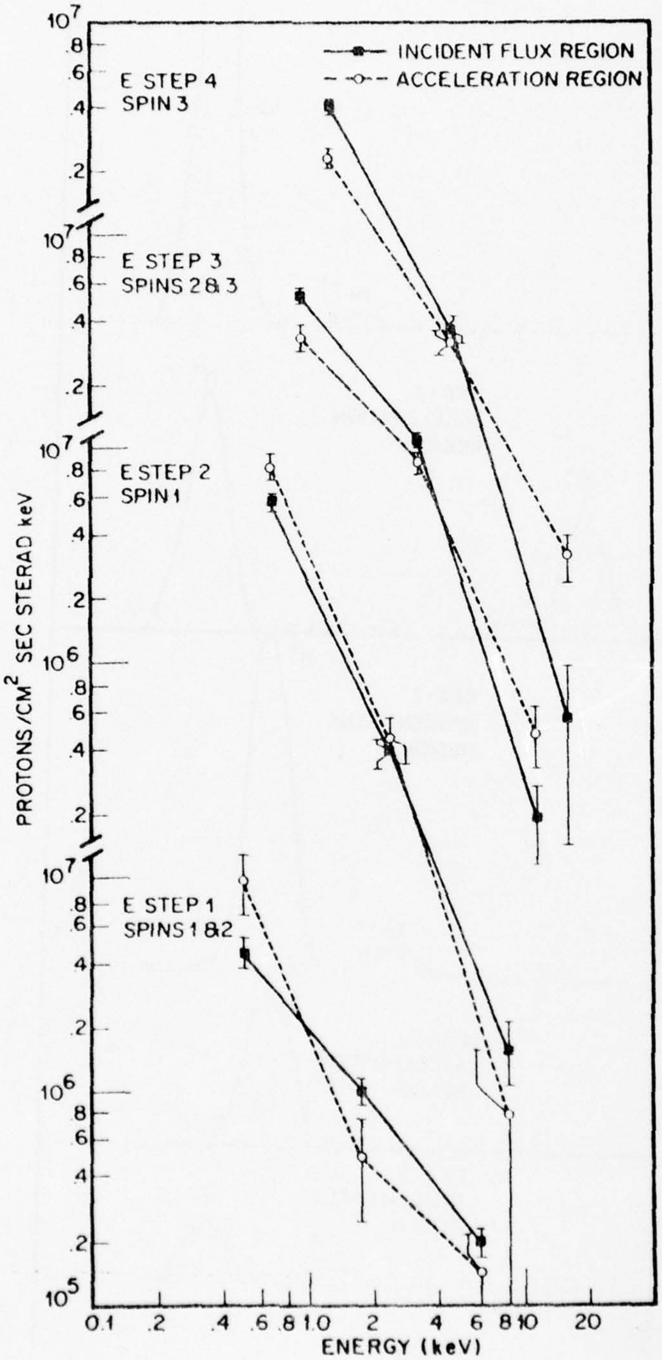

CXA-1
INCIDENT FLUX
REGION
H+
He++
CXA-1
ACCELERATION
REGION
O+
H+
CXA-2
INCIDENT FLUX
REGION
H+
He++
CXA-2
ACCELERATION
REGION
CXA-3
INCIDENT FLUX
REGION
He++
H+
CXA-3
ACCELERATION
REGION
H+
COUNTS
CHANNEL
0
10
20
30

FIGURE 4



INCIDENT FLUX REGION
ACCELERATION REGION
E STEP 4
SPIN 3
E STEP 3
SPINS 2 & 3
E STEP 2
SPIN 1
E STEP 1
SPINS 1 & 2
PROTONS/CM² SEC STERAD keV
ENERGY (keV)

FIGURE 5

BEST AVAILABLE COPY

COMPOSITION OF THE HOT PLASMA NEAR GEOSYNCHRONOUS ALTITUDE

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4 February 1977

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Colorado Springs, Colorado, October 27-29, 1976.

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ABSTRACT

Although there have been no direct measurements of the composition of the hot (keV) plasma at geosynchronous altitudes, the combination of other observations lead to the conclusion that, at least during geomagnetically disturbed periods, there are significant fluxes of ions heavier than protons in this region. Ion composition measurements below 8000 km altitude show upward streaming fluxes of both O^+ and H^+ ions in the L-region of the geosynchronous orbit. These observations are consistent with the conclusion that at least a portion of the total ion fluxes observed at geosynchronous altitude to be highly peaked near the magnetic field lines are heavier than protons and originate in the ionosphere.

1. INTRODUCTION

Quantitative measurements on the ion composition of the hot (keV) plasma near geosynchronous altitude have not yet been performed. Thus, the plasma composition in this region of the magnetosphere must be inferred primarily from composition information obtained at other locations in the magnetosphere. Prior to the work of Shelley et al.[1] it was generally believed (or assumed) that the dominant ion species in the hot magnetospheric plasma was always hydrogen (H^+) and that the source of the ions was the solar wind. There is increasing evidence that energetic oxygen (O^+) and helium (He^+) ions of ionospheric origin are frequently significant components in the hot plasma and that during geomagnetically disturbed conditions O^+ ions may be the dominant hot plasma ions in some regions of the magnetosphere. Satellite measurements at low altitudes (near 800 km) during magnetic storms have shown that large fluxes of O^+ ions in the energy range 0.7-12 keV are precipitated along with H^+ ions from the magnetosphere at magnetic L-shells corresponding to the region of geosynchronous altitude (Sharp et al.[2,3] and Shelley et al.[4]).

[1] Shelley, E. G., Johnson, R. G., and Sharp, R. D. (1972) Satellite observations of energetic heavy ions during a geomagnetic storm, J. Geophys. Res., 77: 6104.

[2] Sharp, R. D., Johnson, R. G., and Shelley, E. G. (1976): The morphology of energetic O^+ ions during two magnetic storms: Latitudinal variations, J. Geophys. Res., 81: 3292.

[3] Sharp, R. D., Johnson, R. G., and Shelley, E. G. (1976): The morphology of energetic O^+ ions during two magnetic storms: Temporal variations. J. Geophys. Res., 81: 3283.

[4] Shelley, E. G., Johnson, R. G., and Sharp, R. D. (1974): Morphology of energetic O^+ in the magnetosphere, in Magnetospheric Physics, B. M. McCormac, Ed., D. Reidel, Dordrecht, Netherlands, pp 135-139.

Satellite measurements at intermediate altitudes (near 8000 km) have shown that large fluxes of O^+ and H^+ ions in the keV range are being accelerated out of the ionosphere and injected into the magnetosphere over a wide range of magnetic L-shells (Shelley et al.[5], Johnson et al.[6], and Sharp et al.[7]). Under certain impulsive magnetospheric conditions which produce velocity dispersion of the trapped ions, measurements at geosynchronous altitude indicate that ions heavier than protons are present in the kilovolt energy range (McIlwain[8]). Thus, it appears likely that significant fluxes of ions other than protons are present near geosynchronous altitude at least for some magnetospheric conditions. In this paper, discussion of the composition of the hot plasma is limited to particle energies less than 50 keV since the dominant plasma density and energy near geosynchronous altitude is produced by particles in this energy range. Composition measurements at higher energies and their importance to magnetospheric processes have recently been reviewed by Fritz[9].

[5] Shelley, E. G., Sharp, R. D., and Johnson, R. G. (1976), Satellite observations of an ionospheric acceleration mechanism, Geophys. Res. Letters, 3: 654.

[6] Johnson, R. G., Sharp, R. D., and Shelley, E. G. (1976) Characteristics of upward-flowing, energetic (kev) ions during a geomagnetically disturbed period, EOS, 57: 992.

[7] Sharp, R. D., Shelley, E. G., and Johnson, R. G. (1976) Observation of an ionospheric acceleration mechanism producing energetic (keV) ions primarily normal to the geomagnetic field direction, submitted to the J. Geophys. Res.

[8] McIlwain, C. E., Bouncing clusters of ions at seven earth radii, (1976) EOS, 57, 307.

[9] Fritz, T. A. (1976) Ion composition, Proceedings of the International Symposium on Solar-Terrestrial Physics, Vol. II, D. J. Williams, Ed., publ. by American Geophysical Union, pp 716-729.

The importance of knowing the ion composition of the plasma and the detailed energy and angular distributions of the ion species for modeling the secondary emission effects, current balance, sheath characteristics, etc. during spacecraft charging events is discussed in several other papers in this proceeding and will not be reviewed in this paper. However, for highly anisotropic ion fluxes and certain spacecraft configurations it is possible to have limited regions of a spacecraft acquire a large positive potential with respect to the plasma, in contrast to the large negative potential generally observed and discussed. This possibility of large positive potentials will be discussed in conjunction with the observations of intense ion fluxes aligned nearly parallel with the geomagnetic field direction.

For the purpose of the present discussion, the information presented on the composition of the hot plasma in the magnetosphere will be divided into the three general categories of low, intermediate, and high altitude satellite measurements. The reported observations and plasma composition results in these altitude regions are briefly reviewed and their significance to the geosynchronous altitude environment is discussed.

2. OBSERVATIONS AT LOW ALTITUDES

The most extensive measurements on the composition of the hot magnetospheric plasma have been obtained with an ion mass spectrometer aboard the polar orbiting 1971-089A satellite near 800 km. The satellite was three-axis stabilized with one axis always aligned near the earth's radius vector. The ion mass spectrometer was oriented at 55° to the zenith and thus nearly always sampled ions precipitating from the magnetosphere into the atmosphere. The spectrometer covered the energy range from 0.7 to 12 keV and the mass range from 1 to 32 AMU and the data were acquired primarily during the period from October 1971 to December 1972.

The most prominent ion observed other than H^+ was O^+. The O^+ intensities were largest during principal magnetic storms (Shelley et al.[4]) but significant fluxes were also observed during magnetic substorms (Johnson et al.[10]). A detailed study of the morphology of the O^+ ions during the rather classic 17-18 December 1971 magnetic storm has been made and reported in the literature (Sharp et al.[2,3]). Figure 1 from Shelley et al.[1] shows H^+ and O^+ data from 6 consecutive satellite traversals of the nightside (0300 LT) high latitude regions during the main phase of the storm. The ordinate is approximately proportional to the integral number flux in the instrument energy range from 0.7 to 12 keV. The

[10] Johnson, R. G., Sharp, R. D., and Shelley, E. G. (1975) Composition of the hot plasmas in the magnetosphere, in Physics of the Hot Plasma in the Magnetosphere, B. Hultqvist and L. Stenflow, Ed., Plenum Publishing Corp., New York, pp 45-68.

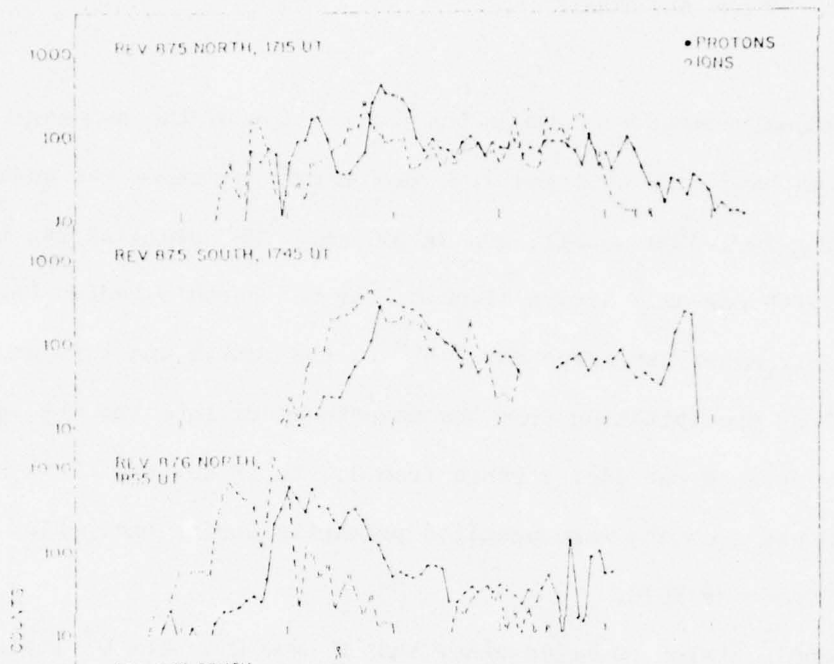

Figure 1. Ion fluxes during the 17 December 1971 magnetic storm (from Shelley et al.[1]).

principal features of note are: 1) the O^+ fluxes at L-shells (near L = 6.6, $\lambda_L = 67^o$) corresponding to geosynchronous altitude can be comparable in intensity to the H^+ fluxes, 2) the latitudinal distributions of both species have significant structure and vary from pass to pass, and 3) at a given location the relative composition of the flux changes from pass to pass.

The locations in magnetic latitude of the O^+ and H^+ precipitation regions throughout the time period of the magnetic storm are shown in Figure 2 (Johnson et al.[10]). The integral energy flux of the O^+ and H^+ ions was computed over the latitudinal range $40^o < \Lambda_L < 80^o$ and the circle for the H^+ ions and the square for the O^+ ions in Figure 2 represents the 50% point in the zone integral with the bars representing the 10% and 90% points in the same integral. From this figure it is seen that significant O^+ precipitation is frequently occurring during the storm at magnetic latitudes (near $\Lambda_L = 67^o$) corresponding to the geosynchronous altitude.

The latitudinal dependence of the average precipitation intensity during the entire period of the storm (0532 UT on 17 December to 1146 UT on 18 December) is shown in Figure 3. It is seen that at magnetic latitudes near 67 degrees the O^+ and H^+ fluxes are comparable when averaged over the storm and that the O^+ ion intensities exceed the proton intensities below 65^o magnetic latitude.

The energy distributions of the precipitating O^+ and H^+ ions were found to be highly variable at all magnetic latitudes (Shelley et al.[1]). The average energy for the O^+ ions in the measured energy range during the storm-time period is shown in Figure 4 and is seen to be about 5 keV near the magnetic latitudes

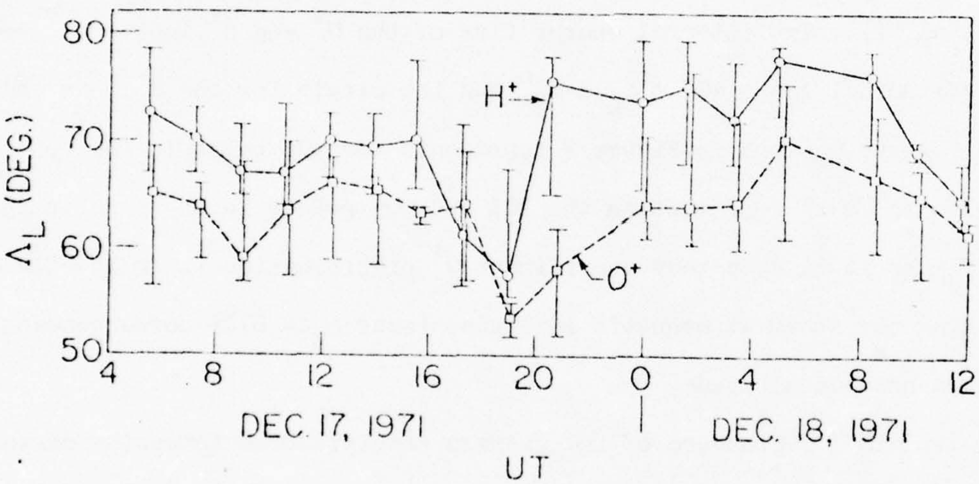

Figure 2. Locations of the precipitation zones of O^+ and H^+ ions during the 17-18 December magnetic storm (from Johnson et al.[10]).

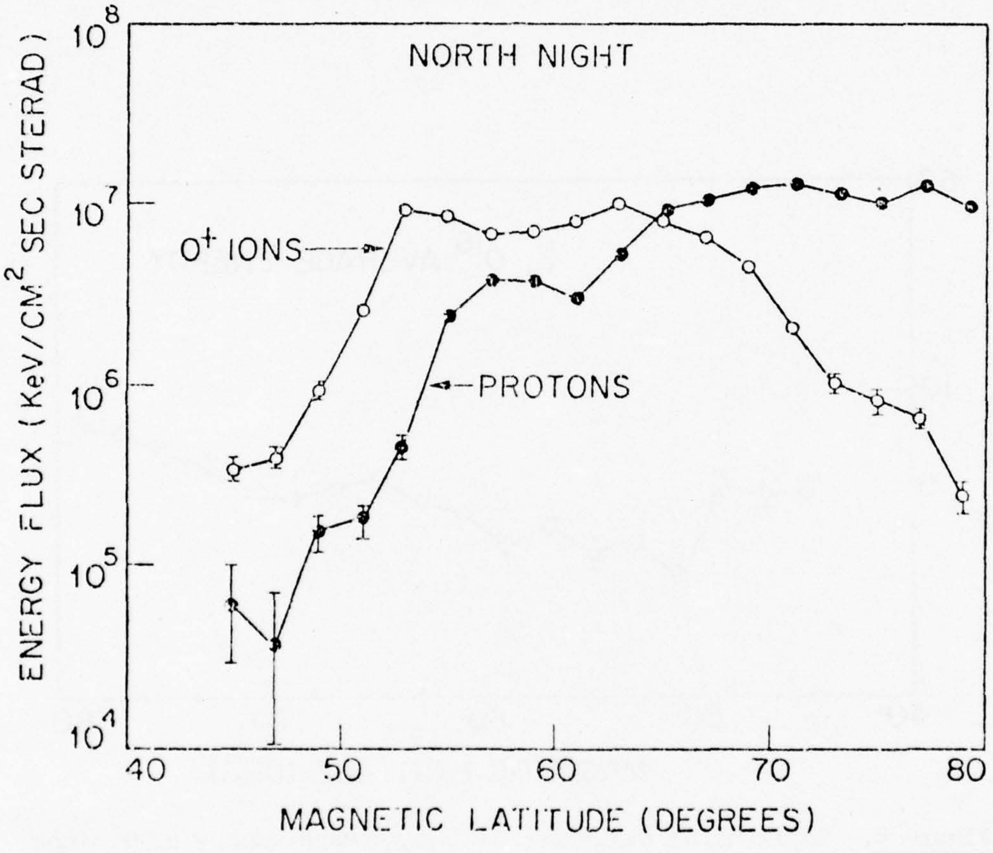

Figure 3. Latitudinal variation of the energy flux of O^+ and H^+ ions during the time period 0532 UT on 17 December to 1146 UT on 18 December 1971 (from Johnson et al.[10]).

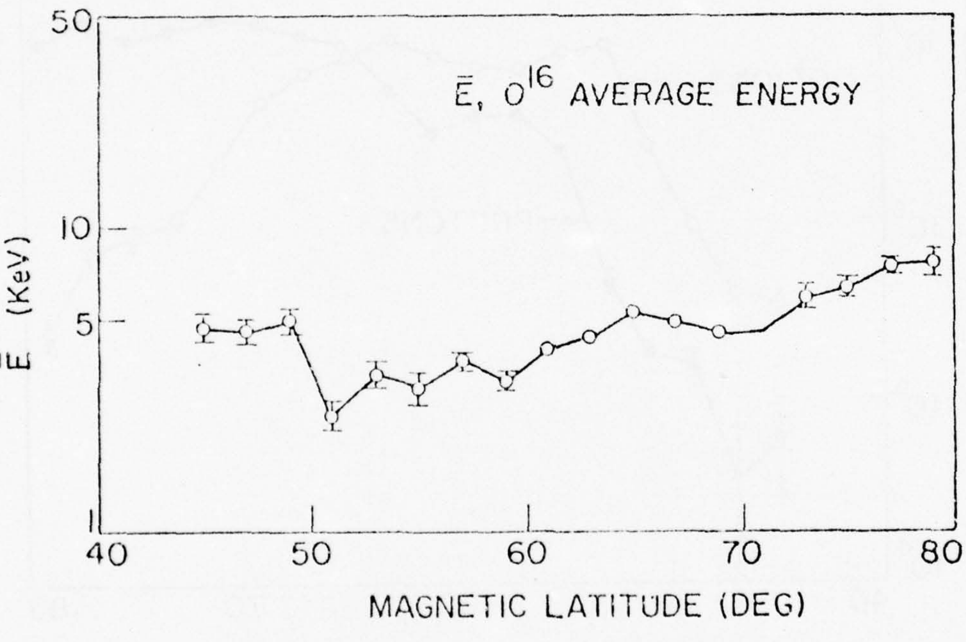

Figure 4. Latitudinal variation of the average energy of O^{+} ions during the time period shown in Figure 2 (from Johnson et al.[10]).

appropriate to the geosynchronous location.

To assess the local time dependence of the O^+ precipitation during magnetic storms, a synoptic study was made of data from one year's operation of the energetic ion mass spectrometer aboard the 1971-089A satellite (Shelley et al.[4]). Data were utilized from three orbits in each of eleven principal magnetic storms during the period from December 1971 to November 1972. O^+ ion precipitation was observed during each of the storms. The latitudinal extent and local magnetic time distribution of the O^+ regions are shown in Figure 5 from Shelley et al.[4]. The dot indicates the position of the maximum flux intensity during each pass and the lines indicate the position of the pass during which the flux was above the spectrometer sensitivity threshold of about 2×10^5 ions/cm^2-sec-sr. From these data, it is seen that O^+ fluxes were frequently observed at the geosynchronous L-shells at essentially all local times, except for possibly a few hours near 1200 local magnetic time. The peak fluxes were typically in the range 5×10^5 to 4×10^7/cm^2-sec-sr. The O^+ peak intensities near noon were found to be, on the average, about a factor of ten lower than near the midnight sector (Shelley et al.[4]).

Precipitating O^+ fluxes have been observed with the same spectrometer in association with magnetic substorms (Johnson et al.[10]). The peak intensities were in the range of 3×10^5 to 3×10^6 ions/cm^2-sec-sr and were observed at L-shells corresponding to the geosynchronous altitude.

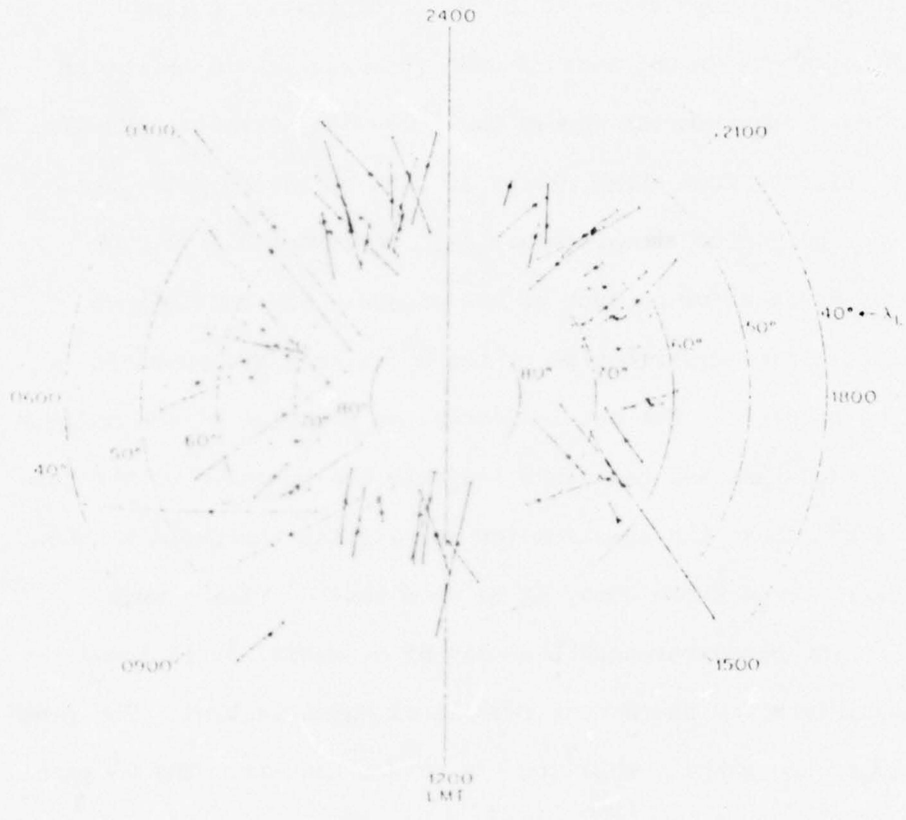

Figure 5. Polar plot in invariant latitude and magnetic local time of the regions of observed O^+ precipitation during 11 major storms (from Shelley et al.[4]).

Precipitating fluxes of He^{+} and He^{++} were also observed with the 1971-089A satellite on L-shells corresponding to geosynchronous altitude (Johnson et al.[11]; Sharp et al.[12]). The He^{+} and He^{++} fluxes were observed much less frequently than the O^{+} fluxes and their intensities were much less than those typically observed for the O^{+} ions during magnetic storms. However, based on ion lifetime considerations, Tinsely[13] and Lyons and Evans[14] conclude that He^{+} is most likely the dominant ion in the late-time ring current.

Rocket measurements with ion mass spectrometer at altitudes below 1000 km have also shown the presence of energetic He^{++} and O^{+} ions in the magnetosphere (Whalen and McDiarmid[15] and Lynch et al.[16]). These measurements have been made near Ft. Churchill, Canada and thus have been limited to the high magnetic latitudes near L = 9.

[11] Johnson, R. G., Sharp, R. D., and Shelley, E. G. (1974) The discovery of energetic He^{+} ions in the magnetosphere, J. Geophys. Res., 79: 3135.

[12] Sharp, R. D., Johnson, R. G., and Shelley, E. G. (1974) Satellite measurements of auroral alpha particles, J. Geophys. Res., 79: 5167.

[13] Tinsely, B. A. (1976) Evidence that the recovery phase ring current consists of helium ions, J. Geophys. Res., 81: 6193.

[14] Lyons, L. R., and Evans D. S. (1976) The inconsistency between proton charge exchange and the observed ring current decay, J. Geophys. Res., 81: 6197.

[15] Whalen, B. A., and McDiarmid, I. B. (1972) Further low-energy auroral ion composition measurements, J. Geophys. Res., 77: 1306.

[16] Lynch, J., Pulliam, D., Leach, R., and Scherb, F. (1976) The charge spectrum of positive ions in a hydrogen aurora, J. Geophys. Res., 81: 1264.

3. OBSERVATIONS AT INTERMEDIATE ALTITUDES

Preliminary results are now available from an energetic ion mass spectrometer experiment aboard the spacecraft 1976-65B which is in an elliptical polar orbit with apogee near 8000 km (Shelley et al.[5]). The spacecraft is spinning and provides for the first time detailed pitch angle distribution measurements with identifiable mass-per-unit-charge. The experiment covers the energy-per-unit-charge range from 0.5 to 16 keV and the mass range from 1 to 150 AMU.

O^+ and H^+ ions are frequently observed streaming upward along magnetic field lines with intensities of both O^+ and H^+ often found to be near 10^8 ions/cm^2-sec-sr. The upward streaming ions have been observed over all the local magnetic time range thus far examined from 0900 to 2200 hours. The latitude distributions of these ions have not been determined in detail but during magnetic storms upward streaming fluxes in the evening sector are frequently observed in the range of 65° to 70° magnetic latitude, thus spanning the L-shell regions at geosynchronous altitude. During the 24 August 1976 magnetic storm upward streaming H^+ and O^+ fluxes were observed continuously over a latitudinal extent of several hundred kilometers. The energy distributions of the ions extended to at least 8.5 keV and the O^+ energy spectrums were frequently harder than the H^+ spectrums (Johnson et al.[6]). The upward streaming ion fluxes are observed during quiet as well as disturbed magnetic periods.

The angular distributions of the upstreaming ions are often sharply peaked along the magnetic field lines. A typical example of this (Shelley et al.[5]) is shown in Figure 6 for a segment of data acquired in the northern auroral region at a local time of about 21 hours on 13 July 1976. The relative flux intensities of the O^+ and H^+ ions are plotted versus time and can be compared with the look direction of the instrument relative to the magnetic field direction (upper panel) as determined from the on-board magnetometer. The energy-per-unit-charge of the measured ions is also indicated above the O^+ panel. One can readily see the sharply peaked angular distributions of both the O^+ and H^+ ions. The peak upstreaming O^+ flux observed corresponds to about 10^8 ions/cm^2-sec-sr-keV. The lowest panel shows the response of the electron detector which sampled the energy range $0.33 \leq E \leq 1.28$ keV. The deep minima in the electron flux at pitch angles corresponding to the atmospheric loss cones are clearly evident at the same locations as the ion peaks.

The foregoing type of angular distributions for the ions and electrons could lead to a net positive upward streaming flux at angles near the magnetic field direction. If an anistropic flux of this type is incident on a spacecraft with a hole in the outer skin, then a non-conducting surface on a component inside the skin and on the same magnetic field line as the hole will become positively charged providing the hole subtends an angle from the component surface equal to or less than the pitch angle range over which the positive ion flux is larger than the electron flux. Assuming that the electron flux is

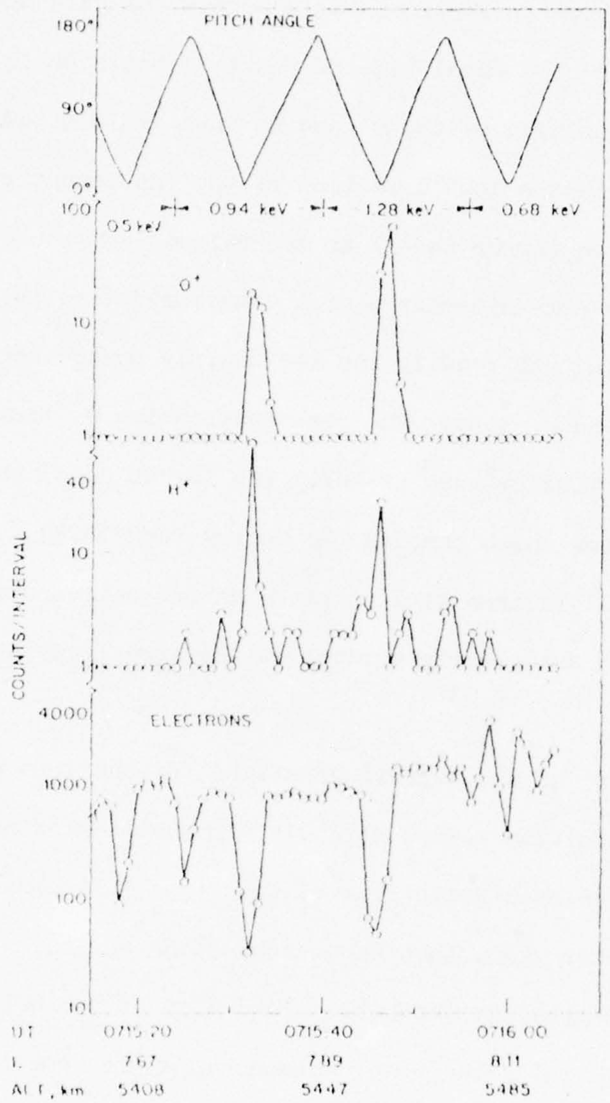

Figure 5. Data from Revolution 35 on July 13, 1976. The upper panel shows the pitch angle of the center of the instrument field of view. The two center panels show data from the mass spectrometer at the indicated energies, and the lower panel shows electron fluxes in the energy range from 0.37 to 1.28 keV. The relative temporal precision of the plots is about one second (from Shelley et al.[5]).

higher than the ion flux at the larger pitch angles (which is typical) then a large negative potential could be formed on the component surface adjacent to a large positive potential. This configuration is illustrated schematically in Figure 7, and to simplify this example, the secondary electron emission from the surface is assumed to be negligible. The surface position L on the component lies along the magnetic field line through the hole in the spacecraft skin. Angles l_1 and l_2 are taken to be less than the pitch angle range over which the ion flux is greater than the electron flux so that a positive potential will occur at position L. Position N illustrates a surface region at angles between n_1 and n_2 to the magnetic field direction where the electron flux is larger than the ion flux. At this position a negative potential will occur. At some position, M, between N and L the electron and ion fluxes will be equal and a zero potential will occur. It can be seen that the surface charging at each position on the surface is related to the pitch angles subtended at the hole in the skin and thus, in analogy to pinhole cameras for electromagnetic radiations, this will be referred to as the "pinhole camera charging effect". Although it has been illustrated for a net positive flux along the field line, an anisotropic electron flux will also produce a potential gradient across the surface in essentially the same way. Another case to consider in relation to the pinhole camera charging effect is the one in which the spacecraft skin is charged highly negative. In this case, the anisotropic ion flux could be produced by the acceleration of the ions along the field line by the spacecraft surface potential while the electron flux reaching the spacecraft surface at angles near the magnetic field direction is reduced by the negative potential of the surface.

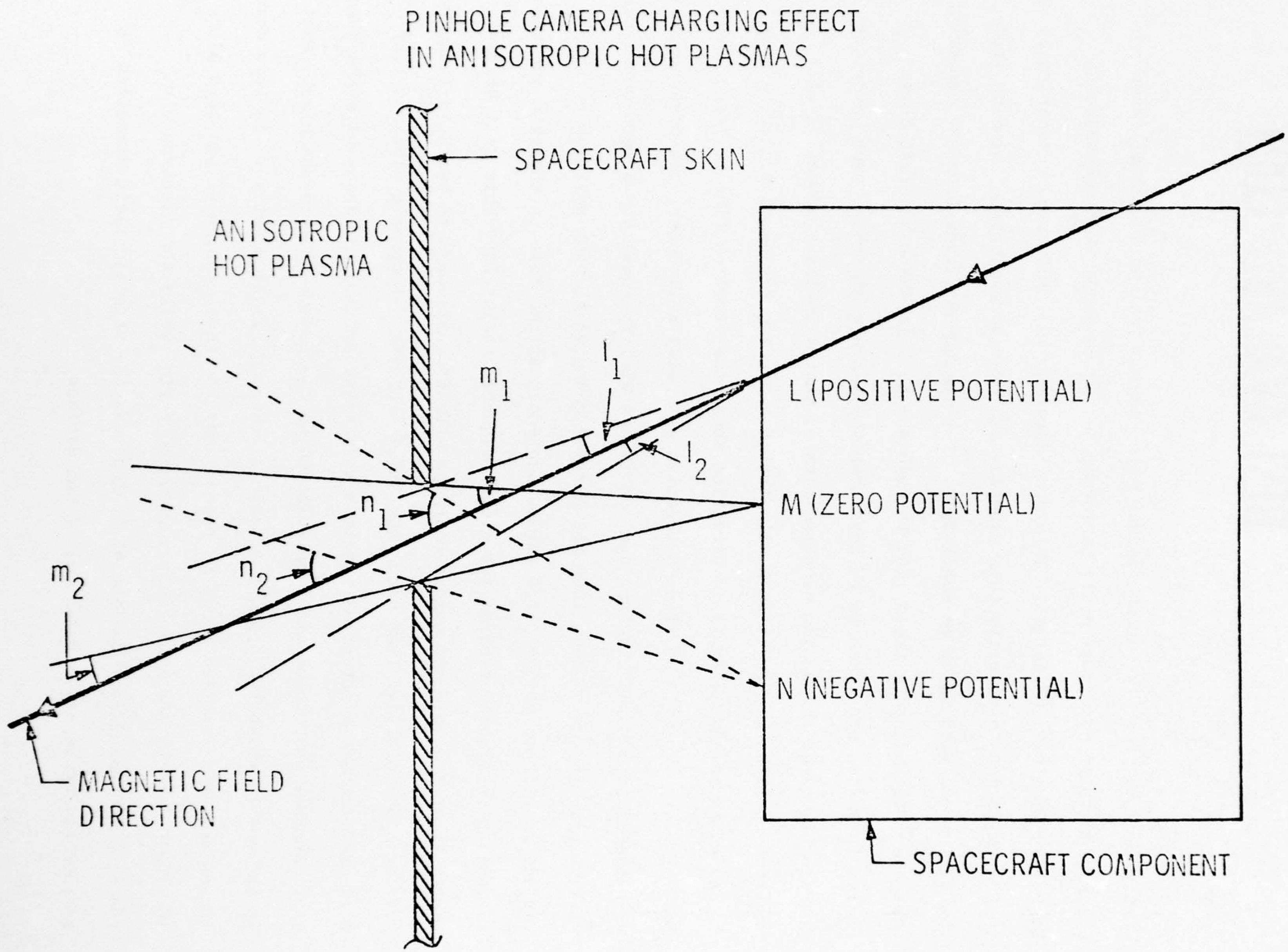

Figure 7. A schematic drawing illustrating the geometry for the pinhole camera charging effect in anisotropic hot plasmas.

4. OBSERVATIONS AT SYNCHRONOUS ALTITUDE

Extensive measurements on the electron and total ion characteristics of the hot plasma at geosynchronous altitude have been made with instruments aboard the ATS-5 and ATS-6 satellites (Deforest[17] and McIllwain[18]). Although the instrumentation could not distinguish the ion species, analysis of bouncing clusters of ions during some types of transient events can provide information on the ion masses. In two cases, McIllwain[8] reports that the data are best fit if He^+ or O^+ ions are assumed for the cluster ions, but quantitative values for the fluxes are not reported.

Angular distribution measurements on the ATS-6 satellite show that the ion fluxes below 10 keV are often enhanced at small pitch angles (McIllwain[18] and Mauk and McIllwain[19]). An example of this enhancement is shown in Figure 8 from the paper by Mauk and McIllwain[19]. It is seen that the enhancement extends to 6.2 keV and to pitch angles well outside the region of the atmospheric loss cone of about 5°. Enhancement of the ions at small pitch angles at synchronous altitude is consistent with the continued upward flow of the upward

17 Deforest, S. E. (1977) The plasma environment at geosynchronous altitude, This proceedings

18 McIllwain, C. E. (1975) Auroral electron beams near the magnetic equator, Physics of the Hot Plasma in the Magnetosphere, B. Hultqvist and L. Stenflo, Ed., Plenum Publ. Corp., New York, 91.

19 Mauk, B. H., and McIlwain, C. E. (1975) ATS-6 UCSD auroral particles experiment, IEEE Trans. on Aerospace and Electronic Systems, Vol. AES-11, 1125.

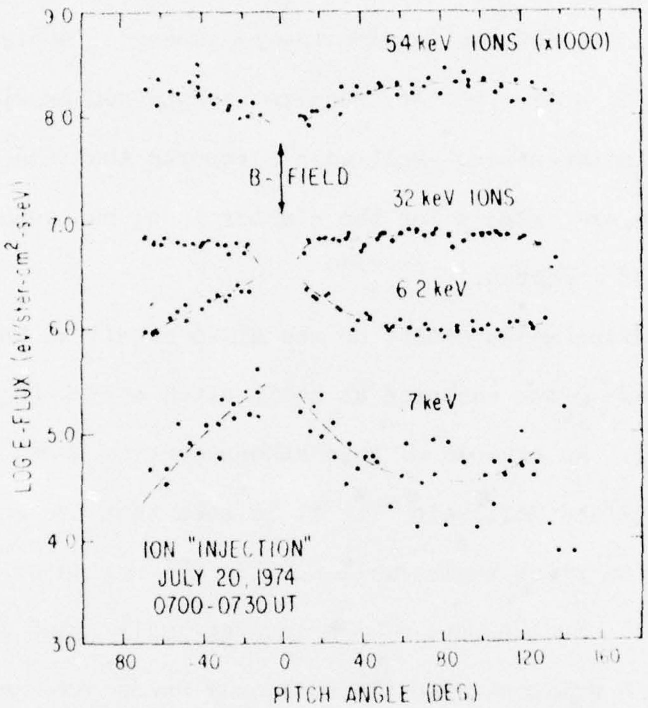

Figure 8. Ion pitch angle distributions as measured on the ATS-6 synchronous satellite during an ion injection event on 20 July 1974 (from Mauk and McIlwain[19]).

streaming ionospheric ions observed at lower altitudes and discussed in the preceeding section. Thus, it is reasonable to expect similar ion composition in the peaked ion fluxes at synchronous altitude as is found in the upward flowing ions on the same L-shells at the lower altitudes.

McIllwain[2] also notes that simultaneous ion and electron field-aligned beams at the higher energies do <u>not</u> seem to occur. Thus, the pinhole camera charging effect discussed in the previous section may be particularly applicable near geosynchronous altitudes.

5. SUMMARY

Plasma composition measurements at low altitudes show that relatively large fluxes of O^+ ions as well as H^+ ions are precipitated from the magnetosphere at magnetic L-shells corresponding to geosynchronous altitude. Upward streaming O^+ and H^+ ions from the ionosphere are also observed on field lines threading the geosynchronous location. Observations at synchronous altitude of ion fluxes highly peaked at small pitch angles are consistent with the ionosphere as the source of the ions. Thus, although there are no definitive measurements of the composition of the hot plasma near geosynchronous altitude, other observations strongly support the conclusion that at least during magnetic storms significant fluxes of ions heavier than protons are also present there.

6. ACKNOWLEDGEMENTS

This work was supported in part by the Atmospheric Sciences Section of the National Science Foundation under Grant DES 74-21834.

SATELLITE OBSERVATIONS OF AN IONOSPHERIC ACCELERATION MECHANISM

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R. D. Sharp
R. G. Johnson (all at: Space Sciences Laboratory, Lockheed Palo Alto Research Laboratory, Palo Alto, California 94304)

A satellite-borne energetic ion mass spectrometer experiment has detected fluxes of O^+ and H^+ ions flowing up out of the ionosphere in the auroral and polar regions. The observed ions have energies in the keV range, narrow pitch-angle distributions aligned along the magnetic field direction and peak flux intensities of the order of 10^8 $(cm^2\text{-sec-sterad-keV})^{-1}$. The observations were made at altitudes between 5000 and 8000 km on both the day and nightsides of the earth.

1. 071063SHELLEY
2. 1976 Fall Annual Meeting
3. Solar Planetary Relationships (Magnetospheric Physics)
4. No
5. No
6. No
7. 0%
8. Bill to:

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9. Lockheed Purchase Order No.: 268465

RECENT RESULTS OF ENERGETIC ION COMPOSITION
MEASUREMENTS IN THE MAGNETOSPHERE

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A newly-launched satellite experiment employing an energetic ion mass spectrometer has detected large fluxes of energetic O^+ and H^+ ions being accelerated up, out of the ionosphere, in the auroral and polar regions. Ion fluxes of the order of 10^8 $(cm^2\text{-sec-sterad-keV})^{-1}$ have been measured with energies in the keV range. The measurements were obtained in the northern hemisphere over an altitude range from about 5000 to 8000 km. Examples of two types of events with significantly different pitch-angle distributions will be presented. In one, the upward-flowing ions were observed with a peak in the angular distribution of about 10° to 20° FWHM antiparallel to the magnetic field direction. In the other, the pitch-angle distribution had dual maxima at about 120° to 140° from the magnetic field direction with a minimum antiparallel to B.

Recent results of the further analysis of an earlier body of data from a low-altitude polar-orbiting satellite will also be described. Measurements during the 5 August 1972 magnetic storm showed pronounced peaks in the energy spectrums of precipitating H^+, He^+, and O^+ ions. The energy of the peak increased with increasing magnetic latitude. Within the resolution of the measurements the spectral peak occurred at the same velocity independent of ion species.

Following recent inferences that helium ions might have dominated the ring current during the recovery phase of the December 1971 magnetic storm, a search was made for precipitating helium ions at that time with negative results. The implications of these results to the question of the composition of the ring current will be discussed.

CHARACTERISTICS OF UPWARD-FLOWING, ENERGETIC (keV), IONOSPHERIC IONS DURING A MAGNETICALLY-DISTURBED PERIOD

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Upward-flowing energetic ions of ionospheric origin were observed during a magnetically-disturbed period on August 24, 1976 with a satellite-borne energetic ion mass spectrometer covering the energy range from 0.5 to 16 keV. Oxygen ions and protons were observed with narrow pitch-angle distributions and with peak intensities of the order of 10^8 (cm^2-sec-sterad-keV)$^{-1}$. The ion energies extend to several keV and spatial/temporal changes in the spectrums are common and quite large. The oxygen ion spectrums frequently extend to higher energies than the protons. The upward-flowing ions were observed over a latitudinal extent of several hundred kilometers.

1. 003186JOHNSON
2. 1976 Fall Annual Meeting
3. Solar Planetary Relationships (Magnetospheric Physics)
4. No
5. No
6. No
7. 0%
8. Bill to:

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ENERGETIC (keV) ION COMPOSITION OBSERVATIONS ON THE S3-3 SATELLITE

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Ion composition measurements on the S3-3 satellite are being made over the energy range from 0.5 to 16 keV with an ion mass spectrometer consisting of a Wien velocity filter followed by an electrostatic analyzer. H^+, He^+, He^{++} and O^+ ion have been observed. O^+ and H^+ ions are frequently observed streaming upward along the magnetic field direction. The ion energies are typically in the few keV range but have been observed up to 16 keV. Upward streaming He^+ ions are also observed but less frequently and with lower fluxes than the O^+ or H^+ ions. O^+ fluxes comparable to the H^+ fluxes were observed in the ring current near 5000 km at $L = 3$ to 4 during the main phase of the 28 December 1976 magnetic storm.

1. 003186JOHNSON
2. 1977 Spring Meeting
3. Magnetospheric Physics
4. Special session on the S3-3 satellite results
5. No
6. No
7. 5%
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ANGULAR DISTRIBUTION CHARACTERISTICS OF UP-STREAMING ENERGETIC (keV) O^+ AND H^+ IONS

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R. G. Johnson
E. G. Shelley
R. D. Sharp (all at Space Sciences Laboratory, Lockheed Research Laboratory, Palo Alto, California 94304)
(Sponsor: Dr. Richard D. Sharp)

Measurements of the pitch-angle distributions of energetic (keV) O^+ and H^+ ions have been obtained with an ion mass spectrometer aboard the S3-3 (1976-65B) spacecraft. Upstreaming O^+ and H^+ ions are frequently observed in the keV energy range with intensities up to about 5×10^8 ions/cm^2-sec-ster-keV. The O^+ and H^+ angular distributions in a few upstreaming events have been analyzed in detail to investigate the dependence of the distributions on the mass and energy of the ions. Some events have highly field-aligned distributions with widths less than the instrument angular resolution of about 4^o FWHM for both O^+ and H^+ ions. In other events, the angular distributions are mass dependent with the O^+ distributions usually being wider than the H^+ distributions. Some constraints on the processes producing the observed ion fluxes are inferred from the variations of the source cone width with mass and energy.

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1. 002641SHARP
2. 1977 Spring Meeting
3. Magnetospheric Physics
4. S3-3 Special Session
5. No
6. No
7. 0
8. Technical Information Center
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ELECTROSTATIC POTENTIAL DIFFERENCES ALONG MAGNETIC FIELD INFERRED FROM SATELLITE MEASUREMENTS OF ELECTRON AND ION DISTRIBUTIONS

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Upward-streaming H^+ and O^+ ions in the keV range, closely aligned with the magnetic field, were observed with the 1976-65B, polar-orbiting satellite at 1054 UT on September 15, 1976 at 18 HR MLT, 70° invariant latitude, and at an altitude of 7820 km. The ions were observed during three spin periods (distance ~ 240 km) while the satellite was moving toward higher latitudes. Electrostatic potential differences along the magnetic field, above and below the satellite, were inferred from pitch-angle and energy measurements of electrons (70 eV - 24 keV) made prior to and during the streaming-ion observations. The inferred electric field was directed upward. The potential difference below the satellite was determined from (i) the widening of the loss cones of the electrons, and (ii) the deepening of the loss cones (i.e., the depression of the backscattered flux). The independent determinations, (i) and (ii), are in good agreement with each other but not sufficient to account for the energies of the ions. The potential difference above the satellite was inferred from (i) its effect on the "field-free" electron distribution which was assumed to be the one measured just equatorward of the ions, and (ii) observations of electrons trapped between the magnetic mirror below the satellite and the electric mirror above. For each of the spin periods during which the ions were present, the potential differences below the satellite was found to be 1.5 kV, 3.7 kV, and ~ 1.5 kV, respectively. Above the satellite, the potential difference increased with latitude, being about 0.5 kV on the second spin period.

1. 002641SHARP
2. 1977 Spring Meeting
3. Magnetospheric Physics
4. S3-3 Special Session
5. No
6. No
7. 0
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THE MORPHOLOGY OF UPWARD-FLOWING FIELD-ALIGNED ENERGETIC ION FLUXES

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The inferred signatures of magnetic field-aligned electrostatic potential differences in the several kilovolt range have been observed in the data from an energetic ion and electron spectrometer on the S3-3 (1976-65B) satellite. Large fluxes of H^+ and O^+ ions are frequently found streaming up out of the ionosphere with energies up to 16 keV in a region between invariant latitudes of 60°-80° N and above 5000 km in altitude. The latitudinal width of these upstreaming ion events has been observed to vary from less than a degree to 10 degrees. The pitch-angle distributions are peaked along the magnetic field direction with source cone widths ranging from a few degrees up to $\sim \pi/2$ (full width). The events have been found in about 70% of all the orbits for which data have been acquired extending over a 2-1/2 month period covering the magnetic local time interval from 0900 to 2300 and the magnetic activity range from 0 to 6 in K_p. First results indicate that the field-aligned fluxes out of the ionosphere are a persistent though highly variable phenomena generally occurring in a region near the observed poleward edge of the more energetic ($\sim$ 10 keV) electron precipitation region.

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OBSERVATION OF IONS OF IONOSPHERIC ORIGIN IN THE STORM-TIME RING CURRENT

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SIII 1b

Data on the composition of plasma in the earth's magnetosphere in the energy range 0.5 to 16 keV is being acquired with an ion mass spectrometer aboard the 1976-065B satellite. The satellite is in an 82° inclination orbit, with an initial perigee of 260 km and apogee of 8060 km, and is spinning such that pitch angle data are obtained for the ions. During the main phase of the magnetic storm on 29 December 1976, relatively large fluxes of trapped O^+ and H^+ ions were observed in the region $L = 3$ to $L = 4$ at altitudes near 5000 km. O^+ and H^+ ions were observed over the full energy range of the instrument with the H^+ spectrums typically being harder than the O^+ spectrums. On the first pass through the $L = 3$ to $L = 4$ region, the O^+ number density was about twice that of H^+ and the energy densities were about equal within the instrument energy range. He^+ fluxes were also observed during the main phase but the intensities were small compared to the O^+ fluxes. Trapped O^+ fluxes have also been observed during other magnetic storms and at pitch angles corresponding to equatorial pitch angles up to about 45°.

DISTRIBUTION OF ELECTROSTATIC POTENTIAL ALONG MAGNETIC FIELD INFERRED FROM OBSERVATIONS OF ELECTRON AND ION FLUXES

J.B. Cladis

R.D. Sharp (both at Space Sciences Laboratory, Lockheed Research Laboratory, Palo Alto, California 94304)

Large-scale electric fields, directed upward along the magnetic field, have been inferred from several sets of data on the pitch-angle and energy distributions of electrons and ions obtained at high invariant latitudes ($\geq 65^{\circ}$) and altitudes (~ 6000 km) with the polar-orbiting 1976-65B satellite. The analysis utilized data taken while H^+ and O^+ ions in the keV range were observed to move upward, closely aligned with the magnetic field. The electrostatic potential differences below the satellite were determined not only from the energies of the streaming ions but also from widths and depths of the electron loss cones. Potentials to about 4 kV were computed in this manner. The distributions of the potentials along the magnetic field were estimated from the quasi-neutrality condition, equating along the magnetic field the ion and electron number densities obtained by integrating over the velocity distributions of the observed particles.

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(2) SIII 3d

OBSERVATIONS OF IONS OF SOLAR WIND ORIGIN IN THE INNER MAGNETOSPHERE

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Data on the hot plasma composition in the earth's magnetosphere in the energy range 0.5 to 16 keV is being acquired with an ion mass spectrometer aboard the 1976-065B satellite. The satellite is in an 82° inclination orbit, with perigee near 260 km and apogee near 8060 km, and is spinning such that pitch angle data are obtained for the ions. The ion composition during selected magnetically quiet-time periods ($K_p < 3_o$) in December 1976 has been investigated in the region of the quiet time ring current at altitudes below 8000 km in the midnight sector. He^{++} ions were observed in several passes and in one case they were found as low as L = 5.5 which was near the low latitude edge of the plasma sheet electrons. These observations show that solar wind ions are entering the magnetosphere and are being transported to relatively low L-shells in the magnetosphere during magnetically quiet times.

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